THE HARD QUESTION OF MATTER

This chapter establishes a contemporary portrait of the material realm. Moving from a classical worldview through to quantum and nonlinear accounts, it investigates the unknowns and seeds of material rebellion that inform the physical principles of liquid life.
Origin of Atoms

What makes the atom more real [than a ghost] is that it has more allies, and these allies stretch well beyond humans. Experiments testify to the atom’s existence; instruments stabilize it and make it indirectly visible; generations of children learn of it and pass the word along: Brownian motion shows that particles of water are moved by it. The ghost, by contrast, has only a paltry number of allies bearing witness to its reality. But the atom’s allies may one day desert it too. (Harman 2004, 16)

Atoms were formed during an extremely rapid expansion of the universe during the Big Bang, when it went from ‘nothing’ to ‘relative’ infinity around 13.8 billion years ago. In the first three minutes, when temperatures cooled from 100 nonillion Kelvin to one billion Kelvin, the lightest elements were born as protons and neutrons formed deuterium, a stable isotope of hydrogen. Clouds of this primitive matter condensed and collapsed to form the first cosmic bodies in the non-luminous early universe, which swallowed up the high-energy ultraviolet light produced by the earliest galaxies and stars.

Physicists have brilliantly reverse-engineered the algorithms — or the source code — of the universe, but left out their concrete implementation. (Mørch 2017)

Around 150 million to one billion years after the Big Bang, supermassive black holes had sufficiently expanded to take over the reionisation process. As they interacted with other forms of matter and radiation the universe became luminous (Yeager 2017). Around five billion years after cosmogenesis the current expansion of the universe was initiated, and matter started to condense under the space-time warping influence of gravity (Creighton 2015b), which were countered by dark energy’s inflationary influences (Choi 2017). 4.6 billion years ago, our Sun
was formed from a giant, spinning cloud of gas and dust, and at 4.5 billion years, it was encircled by a cloud of hot debris, which cooled and combined into clumps. Congealing into increasingly larger clots, this molten matter formed planetesimals and planets that frequently collided and vaporised each other.

Out of this primordial fluidity, atoms congealed to produce the dissipative systems that shape our dynamic planet.
Structure of Atoms

... it was thought that atoms were rather like the planets orbiting the sun, with electrons (particles of negative electricity) orbiting around a central nucleus, which carried positive electricity. The attraction between the positive and negative electricity was supposed to keep the electrons in their orbits in the same way that the gravitational attraction between the sun and planets keeps the planets in their orbits. The trouble with this was that the laws of mechanics and electricity, before quantum mechanics, predicated that the electrons would lose energy and so spiral inward until they collided with the nucleus. (Hawking 1995, 65–66)

The quest to characterise atoms at the start of the twentieth century, set the scene for new ways of thinking about the material realm. Through this inquiry, experimental evidence that supported non-classical concepts amassed and matter became stranger.

In 1900, Max Planck set out to establish how to create maximum light from light bulbs with minimal energy, but wondered why his black body experiment did not appear to obey his predictions, which were based on the idea of ‘continuous matter’ that behaves like waves. Looking to Boltzmann’s statistical interpretation of the second law of thermodynamics, which suggested that electromagnetic energy could only be emitted in quantised form—i.e., emitted as discrete particles, as an act of despair, he established the foundations for the theory of quantum physics (Kragh 2000). Other theoretical models also emerged during this period such as Niels Bohr’s atomic model, where atoms are made of electrons that circumscribe quantised orbits around a nucleus.

To observe the fundamental particles from which atoms are composed, giant instruments as big as cathedrals were built to accelerate the nuclei of hydrogen atoms to the speed of light in giant underground tunnels. Torn apart at the moment of colli-
sion with lead (or other hydrogen) nuclei fragments, the curved trajectories and tight spirals they leave behind can be used by physicists to calculate the momentum of a particle, and so deduce its identity. This new science of ‘quantum’ physics began to reveal the strange characteristics of infinitesimally small realms, which suggest that matter is not made of solid blocks, but are mostly empty space (De Jesus 2016). Requiring its own ‘quantum mathematics’, e.g., ‘mirror symmetry’ (Dijkgraaf 2017), the realm is divided into two kingdoms which includes bosons, which tend to behave collectively, and fermions, which are individualists that enable reactive chemistry by refusing to occupy the same quantum states (Wilczek 2017). Quantum effects reach beyond the nanoscale and are capable of ‘spooky’ remote entanglements (Einstein, Podolsky and Rosen 1935) and improbable forms of ‘tunnelling’ that shortcut through previously insurmountable energetic barriers (Razavy 2003, 462). In fact, the strange laws of quantum physics, now appear to apply to things of all sizes such as, birds, plants, black holes, and maybe even people (Vedral 2015).
Darkness

... our separateness and isolation are an illusion. We're all made of the same thing — the blown-out pieces of matter formed in the fires of dead stars. (Crouch 2016, 245)

Albert Einstein’s special relativity theory changed the classical physical law that stated matter could not be created or destroyed. His simple and elegant equation described the relationship between matter and energy as \( E = mc^2 \), where mass was reversibly considered as a super-concentrated form of energy that could be released from atoms. Although his equation was not used directly to set off the nuclear fission chain reactions of the 1945 Hiroshima and Nagasaki atomic bombs — it came to epitomise the pinnacle of all Enlightenment knowledge, where humanity could command the fundamental forces of nature in the most absolute manner.

With the rise of quantum science, humanity’s attention to the nature of the world turned from inwards and downwards (Kauffman 2008, 17) to outwards and upwards into the cosmos. Through the new gaze of radio telescopes and particle detectors, it is apparent that our cosmos is mostly a vacuum that comprises 95% dark matter and energy, which does not obey our universal laws. Our understanding of the whole of reality is based solely on our knowledge of the ‘luminous’ matter that makes up only 5% of its substance. This ‘darkness’ is made up of dark energy and dark matter, which have little in common — other than their nature is elusive.

According to the Planck mission team, and based on the standard model of cosmology, the total mass–energy of the known universe contains 4.9% ordinary matter, 68.3% dark energy and 26.8% dark matter. This is a non-luminous

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1 Where \( E \) = the total energy in the system, \( m \) = the atomic mass of an atom and, \( c \) = the speed of light.
hypothetical substance, first proposed by Jan Oort in 1932, as a way of accounting for missing mass in the universe. Its characteristics are inferred from the gravitational effects on visible matter, radiation, and the large-scale structure of the universe. It cannot be seen directly with telescopes, as it does not respond to the presence of light, although it may emit its own unique kind of gamma ray. This may be a fundamental property of an as yet uncharacterized type of subatomic particle, whose discovery is one of the major efforts in particle physics today. So, while there is more dark matter than normal matter in the universe, the most abundant substance is actually dark energy, which may be an innate property of space. (Armstrong 2016, 36)

Dark stars were first proposed by William Thomson (who would become Lord Kelvin), as a way of accounting for dark regions in the sky, where a theoretical form of matter could account for the uneven distribution of cosmic bodies. Henri Poincaré indicated that, theoretically, much more of this ‘dark matter’ than Kelvin supposed should be expected (Bucklin 2017). By studying the Coma galaxy cluster, Fritz Zwicky produced the first evidence for dark matter by deducing that it did not contain enough visible matter to hold it together. Vera Rubin and Kent Ford also calculated that about ten times as much dark matter than luminous matter was needed to account for the characteristics of spiral galaxies (Scoles 2016). Today, the nature of the dark matter particle remains elusive and it is not even clear that there is just one kind of agent at work.

The most widely accepted theory about dark matter is that it largely works to hold the matter in space together. It accounts for galaxies clumping together despite appearing to lack sufficient visible matter to do so. It is made of weakly interacting particles that move about slowly under the influence of gravity but cannot account for all associated phenomena. Justin Khoury and Lasha Berezhani suggest this may be due to a phase change, where most of the time dark matter behaves like conventional cold dark matter, but under other circumstances becomes a su-
perfluid, with zero viscosity. Then again, Erik Verlinde suggests that dark matter may not exist at all, its apparent effects being caused by interactions between dark energy and matter, which generate curved space-time (Wolchover 2016).

Dark energy is *even more elusive* than dark matter, having been deduced by comparing theoretical and actual cosmological observations. Unchanged by time it acts in some way to counter gravity. While there are also no convincing theories about what it might actually be, its existence accounts for why the expansion of the universe appears to be accelerating.

A more recent theory by James Farnes at Oxford University’s e-Research Centre proposes that dark matter and energy can be unified into a fluid that comprises a sea of negative masses, which repels all adjacent matter. All positive mass surf upon this dark substance, which does not thin out over time, as it is continually produced and therefore, does not become diluted as the universe expands (Farnes 2018).

Our understanding of the cosmos is framed by our knowledge of the small amount of luminous matter with which we are familiar, which means our understanding of the cosmos is likely to be incomplete. It is possible that, as our understanding of dark and quantum realms advances, we will discover that matter is even more extraordinary than we have assumed.
One of our joys was to go into our workroom at night; we then perceived on all sides the feeble luminous silhouettes of the bottles or capsules containing our products. It was really a lovely sight and one always new to us. The glowing tubes looked like faint, fairy lights. (Curie and Curie 1923, 187)

The peculiar realm of radiation was discovered by accident. In 1896, Antoine Henri Becquerel, who was intrigued by the capacity of some materials to glow when exposed to sunlight, was hoping to demonstrate a link between these minerals and a new type of electromagnetic radiation discovered by Wilhelm Röntgen, called X-rays. Although he set up an experiment overcast conditions prevented him from studying the fluorescing material (uranyl sulphate) and he placed it in a drawer, so he could observe its behaviour on a sunny day. On returning to the unexposed plate, he discovered strong, clear images, which indicated that the uranium had emitted radiation without recourse to an external source. Later, Marie and Pierre Curie discovered that both radium and polonium could also emit such rays. This invisible radiation, or ‘radioactivity’, was further characterised as a complex phenomenon by Ernest Rutherford, who split its beams into alpha, beta, and gamma particles, which could be classified according to their ability to penetrate matter. Niels Bohr theoretically demonstrated these rays originated from the emission of charged particles, which jumped between the orbits of atomic nuclei, when they were excited by collisions with other agents. The further characterisation of radiation has not lessened its strangeness, which enjoys an odd relationship to matter, since it interacts with matter, is created by matter, can create matter and is emitted by matter, but it is just too ephemeral to ‘be’ matter (Armstrong 2016, 36).

With the discovery of a stranger invisible, massless, almost volumeless material world, the once indivisible atom became
the backdrop against which these subatomic agents could be observed. With further developments in radiation science, charge-carrying explanations were sought for the properties of matter, which identified other kinds of phenomena. Some of which were surprising, like neutrinos, which do not play a major role in the structure of atoms (Lincoln 2017) and not only provided new accounts of atomic identity, but also firmly established quantum physics as a new field of science.
Spooky Reality

The hard problem of matter is distinct from other problems of interpretation in physics. Current physics presents puzzles, such as: How can matter be both particle-like and wave-like? What is quantum wavefunction collapse? Are continuous fields or discrete individuals more fundamental? But these are all questions of how to properly conceive of the structure of reality. The hard problem of matter would arise even if we had answers to all such questions about structure. No matter what structure we are talking about, from the most bizarre and unusual to the perfectly intuitive, there will be a question of how it is non-structurally implemented. (Mørch 2017)

The first steps towards the standard model that is currently used to understand the anatomy of atoms were established by Sheldon Gashow in the 1960s, when he grouped discoveries in quantum field theory into quarks (up, down, charm, strange, top, bottom); leptons (electron, electron neutrino, muon, muon neutrino, tau, tau neutrino), gauge bosons (gluon, photon, Z-boson, W-boson) and the Higgs boson (Glashow 1961). Like Mendeleev’s periodic table, which further advanced the understanding of the combinatorial properties of the atomic realm by formulating the ‘periodic law’ according to eight base types, Gashow’s system is a deductive and predictive instrument, not only establishing the characteristics of known particles, but also predicting the existence of as yet undiscovered ones. For example, since gravity exists, it is counterintuitive that subatomic particles are massless. The light Higgs boson, or other interactions between particles may confer this missing mass and therefore renders the standard model complete. Further concepts like string theory and supersymmetry also aim to fill in these gaps between knowledge and experiment. String theory proposes that fundamental particles are different manifestations of one basic object: a ‘string’. These are one-dimensional point struc-
tures with no internal organisation that become different particles through the way they oscillate in space-time. So, in one direction, we see an electron, and in another, a photon or a quark. String theory predicts that a type of connection, called supersymmetry, exists between particle types despite their almost oppositional character — for example, fermions and bosons and is almost magical in its oddness. Notably, it anticipates the lightest supersymmetric particle that is stable and electrically neutral, which interacts weakly with the particles of the standard model, has exactly the characteristics of dark matter.

It is still not known how these massless specks establish a connection with gravity. While the nature of matter is still being pieced together, the quantum realm is fundamentally counterintuitive and produces strange phenomena. For example, time crystals have been demonstrated, which spontaneously break time translation symmetry and create the possibility of regularly repeating motion without the need for extra energy from external sources (Yao et al. 2017). Other odd nanoparticles called ‘magnetic skyrmions’ behave in ways similar to the atomic ‘knots’ proposed by Lord Kelvin in his model of atomic structure. This followed on from the work of Hermann Helmholtz in the late nineteenth century, who observed that vortices exert forces on each other and their cores act as a line-like filament that can become knotted with others in ways that could not be undone. Inspired by the coupling potential of these fundamental structures, Lord Kelvin proposed an atomic model where atoms were structured like liquids as knots of swirling vortices in the aether (Zyga 2017). Imagine a bath half filled with water, with not one, but lots of plugholes. Now envision how the surface of the water looks as those plugs are pulled. This is how Lord Kelvin imagined the structure of atoms. Unusually, ‘magnetic skyrmions’ can be observed experimentally (Hou et al. 2017), which means they may at some point be manipulated to test new theories such as ‘knotting’ them into various types of stable configurations by twisting a magnetic field (Zyga 2017).

While initial studies of quantum phenomena were assumed to be confined to imperceptibly small and cold realms, by the
late twentieth century these assumptions were challenged through the identification of exotic materials at the macroscale. For example, semi-metals can produce a current when heat and a magnetic field are applied simultaneously (Gooth et al. 2017); their properties cannot be accounted for by classical physics. Perhaps even more striking are findings in the developing field of quantum biology, where physics meets the life sciences and ‘biology emerges from chemistry, which in turn emerges from how atoms and molecules interact in the microscopic realms ruled by quantum probabilities’ (Byrne 2013). While classical quantum experiments take place in the laboratory at temperatures close to absolute zero, biology can process quantum information at room temperature and stabilise coherent quantum states in extremely complex systems for extended periods.

It turns out that organic systems with tailor-made molecules are highly tunable. The trick is to not lose the input data. (Byrne 2013)

For the observed events to take place, they must disobey a fundamental concept known as decoherence, where quantum effects are averaged out at the macroscale. By demonstrating that quantum phenomena can be effective in these unlikely situations, this means that even at relatively hot temperatures typical of living systems (Al-Khalili and McFadden 2014), the individual properties of matter may be — at least in part — contributing to the ‘weird’ nature of matter and life. Schrödinger drew his inferences on the nature of life, specifically, Schrödinger observed that discrete systems are capable of ‘negative entropy’ that enables system reordering and resistance to entropic decay (Schrödinger 2012, 70).
becoming what Schrödinger called ‘quantum jellyfish’, which refers to the anticipated blurriness and featurelessness when many overlapping boundaries exist, which are characteristic of quantum fields.

… nearly every result produce[d] is about the probability of this or that … happening — with usually a great many alternatives. The idea that they be not alternatives but all really happen simultaneously seems lunatic … just impossible … if the laws of nature took this form for … a quarter of an hour, we should find our surroundings rapidly turning into a quagmire, or sort of a featureless jelly, or plasma, all contours becoming blurred, we ourselves probably becoming jelly fish. (Schrödinger 1995, 19)

Nevertheless, the biological domain does not demonstrate the typical paradoxes associated with information processing in quantum physics (Byrne 2013). The practical implications of these findings are far from reaching a consensus view. This is hardly surprising, as the more that is discovered about the quantum realm, the stranger it seems. To establish a relationship with this realm means that decisions about the kind of information that is useful to us have to be made that can challenge our assumptions. Françoise Chatelin cautions that the mathematical philosophical framework underpinning quantum science is also capable of distorting interpretations of experimental findings because the effects of other forces and agencies involved get smaller as objects get larger. Also, unlike classical physics, the sample sizes are also very small and therefore deal with exceptional behaviour, rather than the averaging effects of huge numbers of molecules (Chatelin 2012).

After the experimental discovery of Quantum Mechanics, the strange wave/particle behaviour at the subatomic level was taken by Bohr (1927) as a fiat from Nature. Bohr posited the ‘complementarity’ principle which states that quantum-mechanical results can only be described in
classical but contradictory terms. Therefore a description in space-time precludes any classically causal description, and if classical causality is maintained then the uncertainty principles (Heisenberg) emerges. In other words, subatomic randomness is only the result of looking at things through the lenses of classical causality. The radically dualistic perspective of Bohr accepts as a gift the two contradictory messages sent by Nature. This paradoxical picture fits perfectly in the organic logic … which stems from hyper computation. But it was a constant source of discomfort for the majority of his peers. Therefore Bohr’s view was abandoned for the most easy-to grasp theory of entanglements, which puts randomness at its foundation. (Chatelin 2012, 558–59)

Nevertheless, researchers are beginning to develop experimental approaches that enable us to test our understanding of our idiosyncratic universe in a constant state of flux.
Maxwell’s Demon

... atoms do not swerve a little and initiate the kind of motion which in turn shatters the laws of fate, but leave effect to follow cause inexorably forever, where does that freewill come from that exists in every creature the world over? (Lucretius 2007, 43)

Lucretius introduced the concept of the ‘clinamen’ to discuss the disobedience of the material realm to the laws of physics. He believed that this unpredictable swerve of atoms accounted for the free will of all living things.

James Clerk Maxwell proposed a thought experiment that aimed to contravene the second law of physics, which states that the entropy in a closed system (a box) cannot decrease (Maxwell 1872). Imagining gas at a particular temperature (or pressure) in a sealed environment, he proposed that within this space some molecules were hotter (moving faster) and some cooler (moving slower) than others. Guarding a membrane-like partition with a small trapdoor (a pore-like system) inside the box, was an imaginary intelligent being (later called a ‘demon’ by Lord Kelvin) that could perform ‘work’ without expending energy, by deciding which side of the membrane the gas molecules ended up on. By sorting the mixed gas molecules into an ordered state with lower entropy the demon could contravene the second law of physics (Kelvin 1879).

The word ‘demon,’ which originally in Greek meant a supernatural being, has never been properly used as signifying a real or ideal personification of malignity. Clerk Maxwell’s ‘demon’ is a creature of imagination having certain perfectly well-defined powers of action, purely mechanical in their character, invented to help us to understand the ‘Dissipation of Energy’ in nature. He is a being with no preternatural qualities, and differs from real living animals only in extreme smallness and agility. He can
at pleasure stop, or strike, or push, or pull any single atom of matter, and so moderate its natural course of motion. Endowed ideally with arms and hands and fingers — two hands and ten fingers suffice — he can do as much for atoms as a pianoforte player can do for the keys of the piano — just a little more, he can push or pull each atom in any direction. He cannot create or annul energy; but just as a living animal does, he can store up limited quantities of energy, and reproduce them at will. By operating selectively on individual atoms he can reverse the natural dissipation of energy … (Kelvin 1879, 144)

Both Maxwell and Kelvin concluded that the presence of an intelligent agent in a disordered system could encapsulate life’s thermodynamic disobedience, but in 1929, Hungarian physicist Leo Szilard demonstrated that the demon had to exert energy to sort the molecules into hot or cold groupings, which would not actually violate the second law (Edwards 2010). Maxwell’s demon therefore gives the appearance of violating the second law, without actually contravening it, which is exactly what life manages to do.
Time’s Arrow

An organism does not have a temporal trajectory; it is itself a temporal trajectory. (Nicholson 2018, 22)

In classical physics, time is a reversible phenomenon. It deals with space and the statistical analyses of large numbers outlined by Ludwig Boltzmann, where random events cancel out any behaviours that may appear to contradict the second law of thermodynamics. This banishes time to the realm of phenomenology (Boltzmann 1964).

In the natural realm, time is a material process that operates at small scales in highly localised situations and produces its effects on a paucity of molecules, where statistical analyses cannot iron out any irregularities. In this contrary space, lively matter has the capacity to retain or increase its order. Tim Maudlin observes that standard geometry, which is algebraic and designed for making directionless spaces, considers time to be an artefact of space. In this case, either nothing alters, or events can be reversed (Musser 2017). Drawing on Henri Bergson’s concept of ‘pure duration’, Ilya Prigogine developed a concept of ‘third time’ in physics, where qualitative local changes melt into and permeate one another, without precise outlines. This provided a new model for examining space-time, where time was ‘pure heterogeneity’ (Bergson 2010, 104), rather than a series of successive (linear) occurrences. Third time is therefore characterised by irreversibility, which provides a source of creativity for the living realm and exists in space-time rather than standard geometric space.

Irreversibility can no longer be identified with a mere appearance that would disappear if we had perfect knowledge. Instead, it leads to coherence, to effects that encompass billions and billions of particles. Figuratively speaking, matter at equilibrium, with no arrow of time
is ‘blind,’ but with the arrow of time, it begins to ‘see.’
(Prigogine 1997, 3)
Symmetry Breaking

According to Archemanes the world was created as a result of the synergy of two primal forces. He understood these powerful forces to be eternal and universal. Their synergy would best be described as never-ending consumption — one devours the other, ceaselessly — and the existence of the world is dependent on this. (Tokarczuk 2003, 99)

All natural forces and elementary particles are assumed to have been identical just before the Big Bang. For the universe to have any character, this fundamental symmetry had to be broken, which is an active phenomenon caused by countless small matter/energy fluctuations acting on a system that tip it into an irreversible cascade of events and is at the heart of all meaningful dynamic events.

First, the colour force between quarks broke away from the electroweak interaction. Then, hadrons developed very different masses from leptons. Next, electroweak forces split into two — electromagnetism and the weak force (or weak nuclear force). Out of these moments of asymmetry, an ocean of particle types blossomed, which gave rise to our present reality.

Liquid life is an asymmetric phenomenon (Coleman 1975), where like no longer breeds like, but moves towards a condition of heterogenesis — where, under the influence of time’s irreversible arrow, nothing can be exactly self-similar, so variation in living systems is the norm, not the exception.
Invisible Realms

Aethers were invented for the planets to swim in, to constitute electric atmospheres and magnetic effluvia, to convey sensations from one part of our bodies to another, and so on, until all space had been filled three or four times over with aethers. ... The only aether which has survived is that which was invented by Huygens to explain the propagation of light. (Maxwell 1878)

Perhaps the hardest of all questions for science to answer is not the nature of matter, but of space. If atomism is correct, then it is possible to measure and detect ‘something’, but it is paradoxical to characterise nothing. Nothing must be filled with *something*, which can then be negated and considered ‘nothing’. Such existential conundrums produce material and conceptual blind spots, which they ask us to imagine concepts beyond our knowledge, experience, or ability to verify them and open up a realm of unnamed mysteries, forces, and unexplained phenomena, which cannot be verified directly through our senses, or even by scientific instruments.

While we cannot directly perceive the invisible realm, its effects can sometimes be indirectly encountered like feeling a breeze upon your face, or watching a dust devil dancing. At other times, invisible realms must be deduced where there is no other available explanation, such as dark energy and matter, which seem to be simultaneously holding the universe together and pushing it apart. The invisible realm remains problematic, as to be accounted for, it must be correctly theorised and conjured into existence. Failure to do this means that our knowledge of reality is incomplete, and what we do not know is banished to the realms of speculation, mythology, or wishful thinking.

From the time of Aristotle, nature was said to ‘abhor’ a vacuum, while Parmenides opposed the concept of *creatio ex nihilo*, since the idea of nothingness by definition did not exist. Up until the fourteenth century, the narratives of ‘nothing’ were at-
tributed to supernatural forces, which sprang from demonic, di-
vine, and unknown influences, that were thought to hold reality
together (Barrow 2002, 71–72). These mysterious invisible forces
also shaped our world and even extended beyond the reach of
the cosmos. From an experimental perspective, scholars such
as Al-Farabi began to make vacuums using pumps and closed
containers, which provoked a range of theories accounting for
the contradictory nature of these spaces and how they could ‘ac-
tually’ hold the universe together. For example, Walter Burley
proposed that voids could exist momentarily but were prevent-
ed from collapse by celestial forces. Enlightenment perspectives
took a mathematical view of the paradox of matter and space,
where Descartes proposed that the single essential property of
matter was its ‘extension’ of volumetric space (Descartes 1985).
This separated bodies at a distance and implied the existence
of a continuous medium between them. The idea of invisible
rays and uncharacterised forces inevitably led to disagreements
about their nature. Isaac Newton and Gottfried Wilhelm Leib-
niz differed in their views about the way gravity influenced bod-
ies, Leibniz regarding Newton’s view of remote interactions as
akin to ‘occultism’ (Clarke and Leibniz 1998).

Soon, the idea of force fields and geometric frameworks began
to fill up these invisible realms and everything moved through
a universe filled with an ocean of ubiquitous (uncharacterised)
ethereal fluid. Collectively, these forces were discussed as trans-
mission media or aethers. These space-filling substances and
fields were necessary for the action of bodies, forces, and light to
act upon. However, most of these ideas could not be empirically
validated. For example, the ‘odic’ force, which was proposed by
Baron Carl von Reichenbach as a vital substance that permeated
crystals, magnets, and living things, could be detected through
the senses. Reichenbach believed that some people were more
predisposed to these forces than others and could be seen as a
field gliding spectacularly along magnets and crystals in total
darkness by sensitive individuals.

While many ‘invisible forces’ were debunked, numerous
paradoxes of the invisible realms remain. Isaac Newton’s laws of
gravity — a cornerstone of physics — remain mysterious, since the hypothetical fundamental gravity-carrying particle, or graviton, has not been identified. Others, such as the luminiferous aether proposed by Christiaan Huygens that could be traversed by light, steadily gained credibility and led to the discovery of electromagnetic phenomena.

It is possible that the fundamental assumptions of atomism leave blind spots in our conception of reality, and may even prevent our complete characterisation of the cosmos. For example, the influence and relevance of dark energy and matter currently exceeds the capacity of our philosophical and experimental apparatuses to ascertain. While this should not preclude investigation of the phenomena, our discoveries are anticipating a particular set of observations that place them within an existing understanding of reality. Alternative ways of conceiving the world are vital for exploring the spandrels of opportunity that exist beyond the limits of a geometrically organised universe, and may help us gain a more complete understanding of the nature of the cosmos.

Physical knowledge has advanced much since 1905, notably by the arrival of quantum mechanics, and the situation [about the scientific plausibility of aether] has again changed. If one examines the question in the light of present-day knowledge, one finds that the aether is no longer ruled out by relativity, and good reasons can now be advanced for postulating an aether … We can now see that we may very well have an aether, subject to quantum mechanics and conformable to relativity, provided we are willing to consider a perfect vacuum as an idealized state, not attainable in practice. From the experimental point of view there does not seem to be any objection to this. We must make some profound alterations to the theoretical idea of the vacuum … Thus, with the new theory of electrodynamics we are rather forced to have an aether. (Dirac 1951)
In an age of quantum theory, the notion of ‘aether’ has become outdated and replaced by more theoretical models and terminology to invoke the character of the void. Even stranger forms of aether than classical physics proposed are explored through the idea of ‘quanta’, or packets of matter. The quantum realm, however, does not assume that space is empty, but already ‘occupied’ by a quantum vacuum. While the term may superficially imply another kind of nothingness, its nature is, unsurprisingly, contradictory. For starters, a quantum vacuum is a very different kind of ‘absence’ than the classical void, as it is not truly empty, but filled with space-time, which has curvature, structure, and is teeming with potential particles, pairs of virtual matter and antimatter units, which are being simultaneously created and destroyed in massive numbers on a quantum scale. This peculiar vacuum also contains ‘quantum foam’, which is made up of many types of electromagnetic fields that permeate space-time, where each domain gives rise to specific subatomic particles — for example, electron fields produce electrons. Quantum foam is imagined as a ubiquitous medium that underpins the propagation of electromagnetic waves by incorporating the transitioning of photons into electrons and positrons — even within the space between galaxies. Since these characterising events are so incredibly small they do not significantly interact with us at the macroscale, so in everyday terms, they can effectively be ignored.

… ‘empty space’ is not what we think it is — it is a soup of a lot of things that average out to zero. Like thermodynamic equilibrium, i.e. ‘no net flow’ is nowhere near the same as ‘no flow’ at all! (De Jesus 2016)

Other theories that characterise the nature of ‘space’ manage to evade the tricky subject of matter altogether. For example, Albert Einstein’s approach to gravity proposes that it is a smooth force

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3 This is an example of radiation (photons) becoming matter (electrons and positrons)
and curvature of space-time that is induced by mass and energy. Therefore, an object’s mass/energy warps space-time — similar to how a rubber sheet is deformed by a heavy body (Creighton 2015b). In this way, Einstein evades the need to discuss the ‘hard question’ of the nature of the material realm.
It would be very difficult to construct a complete unified theory of everything all at one go. So instead we have made progress by finding partial theories. These describe a limited range of happenings and neglect other effects, or approximate them by certain numbers. In chemistry, for example, we can calculate the interactions of atoms without knowing the internal structure of the nucleus of an atom. Ultimately, however, one would hope to find a complete, consistent, unified theory that would include all these particle theories as approximation. The quest for such a theory is known as ‘the unification of physics’. (Hawking 2007, 111)

Quantum theory and general relativity are different world-views, so there is a schism in theoretical physics, which could be healed by a unifying Theory of Everything (TOE). In approaching this quest Paul Dirac developed an equation that decipher the behaviour of an atom moving at relativistic speed, which combined quantum theory and special relativity. However, the outcome posed a significant problem, in that the equation had a positive and a negative solution, which anticipated the existence of antimatter.

From our theoretical picture, we should expect an ordinary electron, with positive energy, to be able to drop into a hole and fill up this hole, the energy being liberated in the form of electromagnetic radiation. This would mean a process in which an electron and a positron annihilate one another. The converse process, namely the creation of an electron and a positron from electromagnetic radiation, should also be able to take place. Such processes appear to have been found experimentally, and are at present being more closely investigated by experimenters. (Dirac 1933)
Such investigations raise profound implications about the conventions we use to understand the universe. For example, attempts to produce a quantum theory of time that brings together the theory of relativity with the quantum realm, suggest that space-time might arise as a side effect of entangled 'quantum bits' (\textit{qubits}) that are situated on the temporal boundaries of the universe (Cowen 2015). Other theories, like 'bootstrapping', which was pioneered by Alexander Polyakov in the 1970s, search for geometric frameworks that can accommodate universal principles within quantum field theory by searching for identical behaviours in diverse materials, where ‘correlation functions’ can be computed. These correlations happen at phase transitions (such as heating iron to the point where it loses its magnetism), where molecules suddenly all exhibit the same behaviours. Such ‘conformal symmetries’ constrain the variables within matter, so that all possible quantum field theories can potentially be unified to generate a quantum TOE. This framework has implications not only for dark matter, but also for space-time and the quantum origin of gravity (Wolchover 2017a).

There’s no telling what insights such a theory would yield. Physicists struggling to marry Einstein with quantum mechanics have already made one startling discovery. In 1971, Russian physicist Yakov Zeldovich guessed that black holes aren’t truly black, but instead combine with quantum-mechanical fluctuations to emit photons and other particles. Stephen Hawking proved the idea three years later, and these emissions are now called Hawking radiation. All fledgling theories of quantum gravity also make a more general and even weirder prediction: the structure of space and time is very different from the gentle curves predicted by general relativity. The American physicist John Wheeler realized in the 1950s that if you look at things on a scale of about 10−35 metres, quantum fluctuations become powerful enough to play tricks with the geometry of the Universe. Space and time break down into ‘fuzziness’ or ‘foaminess’. A spaceship that size could find itself negotiating virtual black
holes, or getting sucked into one wormhole after another and tossed back and forth in time and space. (Brooks 1999, 28)

With such determination to combine the best of both worlds, physicists could be creating a contrary model of reality like the ‘Tycho Brahe solution’, which attempted to reconcile the ancient Ptolemaic system and Copernican cosmology by imagining the Earth at the centre of the universe while all the other planets orbited the sun (Ouellette 2017). It is possible that the range of contradictory findings that characterise the observations of quantum science may simply mean that our current models of the universe are profoundly mistaken.

... if you believe that the universe is not arbitrary, but is governed by definite laws, you ultimately have to combine the partial theories into a complete unified theory that will describe everything in the universe. But there is a fundamental paradox in the search for such a complete unified theory. The ideas about scientific theories outlined ... assume we are rational beings who are free to observe the universe, as we want and to draw logical deductions from what we see. In such a scheme it is reasonable to suppose that we might progress ever closer toward the laws that govern our universe. Yet if there really is a complete unified theory, it would also presumably determine our actions. And so the theory itself would determine the outcome for our search for it! And why should it determine that we come to the right conclusions from the evidence? Might it not equally well determine that we draw the wrong conclusion? Or no conclusion at all? (Hawking 1995, 14)

Provided they are not slammed into competition, the accumulation of differing perspectives on the nature of reality enriches our understanding of it. Since our understanding of matter is incomplete, the pursuit of unifying theories may not be sensible, let alone possible. However, the contradictions that arise from
such a pursuit can offer more complex and nuanced modes of understanding than any one theory alone. Perhaps, as we dwell among the uncertainties, mysteries, and incompleteness of the universe, closer attention to its contradictions to observe what emerges from these uncertain terrains. For example, what does it mean that we best understand the imperceptibly small aspects of reality through the gargantuan scale such as the Large Hadron Collider and how does this relate to human experience? Does quantum entanglement play any role within dissipative structures and, if so, how might this change our understanding of life? To address such questions, our concepts, language, and narratives need to be sufficiently rich to deal with our constantly emerging understanding of reality.
'Pataphysics

To understand 'pataphysics is to fail to understand 'pataphysics. To define it is merely to indicate a possible meaning, which will always be the opposite of another equally possible meaning, which, when diurnally interpolated with the first meaning, will point towards a third meaning which will in turn elude definition because of the fourth element that is missing. What we see of 'pataphysics in the so-called real world is what has been created to provide the evidence of 'pataphysics. It seems to connect with the paradoxes and uncertainties of quantum mechanics, yet it does so through a very different kind of mathematics, a purely imaginary science. (Hugill 2012, 2)

Alfred Jarry’s imaginary science of exceptions resists definitions. 'Pataphysics is intent upon seeking imaginary solutions to real or non-real phenomena, and is remarkable for its purposelessness and unfathomability. Nevertheless, it is a coherent set of ideas and experiments that embrace the specific and irreducible aspects of reality to establish where contradictory and exceptional solutions may be found, such as sailing in a sieve, building a time machine and mathematically calculating the surface area of God (Jarry 1997).

It will already be apparent that definitions of 'pataphysics are to be treated with caution. This is because the very notion of a ‘definition,’ which is a cluster of words that gives the specific sense of a terms that holds true in all (or as nearly all as makes no different) situations, is itself unpataphysical. (Hugill 2012, 3)

'Pataphysics opens up a space for liquid life by enabling the impossible, invisible, imaginary, and contradictory qualities of the living realm to be acknowledged — not as truths but as
paradoxes — and to hold spaces open for experiment that would otherwise be closed by logic and empiricism.
Speck

A vigorous speck. An imperceptible ort of life.
Against the odds.
The chances of life forming by random processes alone based on the possibility of the random synthesis of a small protein are said to be less than one in ten to the power of forty thousand. In other words, the odds against life happening by accident are greater than it occurring once in thirteen billion years — the age of the universe.
Life should not exist.
And yet, a dot of life.
Here (.) (Armstrong, forthcoming 2020)

Against all probability life exists and when it is encountered, it springs from an appropriately lively material condition. The questions missing from the classical worldview of ‘life’ pertain to its native vital materiality, which is a material condition that permeates matter at far-from-equilibrium states and is capable of being incorporated into existing and new assemblages of participatory matter. ‘Vital materialist’ Jane Bennett proposes that the ‘life-principle that animates matter, exists only when in a relationship with matter, but is not itself of a material nature’ (Bennett 2010b, 47–48). In providing examples of vital materiality from the inanimate world — where ‘glove, pollen, (unblemished dead) rat, cap, stick … comman[d] attention in their own right, as existents in excess of their association with human meaning, habits or projects …’ (Bennett 2010b, 4) — she responds to the oddness of a ‘lively’ material composition. Bennett’s desire to reunify inert matter with a vital essence, (re)transposes this liveliness into an ephemeral realm, which beyond its compelling description is nonetheless complicit with the logic of the bête machine.

Appreciating that matter itself is a fundamentally strange actor that appears disobedient to classical laws (see sections 09.9 and 08.10), does not mean that anything goes. Rather, a non-
classical set of principles also govern ‘actual’ material agency. Observations made throughout the twentieth century indicate that innate vitality is bestowed upon the material realm without invoking spiritual infusions through the laws of quantum physics, the passage of ‘third time’ and ‘dissipative adaptation’. Since energy flows freely through agentised matter in unidirectional time, it can also dynamically alter its program, which raises questions about the origins of ‘mind’. These operations are not self-contained, but are fundamentally open and directly coupled to the environment. Moreover, the molecular interactions that comprise these material expressions, such as dissipative structures, are shaped by the transformations encoded by their spatial configuration, elemental character, laws of physics, chemistry, and, also, by their context. Furthermore, these behaviours and transformations have also been independently shown to become even more complex — whether they are directly observed, or not (Prigogine 1997).

We now know that irreversibility leads to a host of novel phenomena, such as vortex formation, chemical oscillations, and laser light, all illustrating the essential constructive role of the arrow of time … The claim that the arrow of time is ‘only phenomenological,’ or subjective, is therefore absurd. We are actually the children of the arrow of time, of evolutions, not its progenitors. (Prigogine 1997, 3)

To engage with such lively entities is not to subdue, but to engage and provoke them. Given that the material realm is stranger than our classical laws attest, and the ‘emergent’ properties arise from agents that cannot be meaningfully reduced into their components, then it is possible that, as yet uncharacterised, forces or events may also be in play. Such perspectives do not negate the soul substance that is necessary for ‘life’ but through its irreducibility and inseparability from matter, as a unique and fundamental material property of the (luminous) cosmos.
The role of the observer was a necessary concept in the introduction of irreversibility, or the flow of time, into quantum theory. But once it is shown that instability breaks time symmetry, the observer is no longer essential. In solving the time paradox, we also solve the quantum paradox and obtain a new, realistic formulation of quantum theory. This does not mean a return to classical deterministic orthodoxy; on the contrary, we go beyond the certitudes associated with the traditional laws of quantum theory and emphasize the fundamental role of probabilities. (Prigogine 1997, 5)